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Tribological properties of DLC films prepared by magnetron sputtering

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Abstract

Two kinds of diamond-like carbon films containing Ti, C and Ti, Cr, C were prepared by magnetron sputtering PVD. The microstructure and elemental composition of the films were characterized by atomic-force microscope (AFM) and auger electron spectrometer (AES), the hardness and modulus were analyzed by nano-indentation, and the tribological properties of the DLC films sliding against GCr15 ball at various loads were measured on a universal reciprocating friction and wear tester. It was found that a compact and gradient diamond-like carbon film was formed on the Si surface by magnetron sputtering. Ti, C DLC films showed excellent wear resistance because of higher value of H/E, the friction coefficient was 0.1~0.2 at various loads and the wear rate was in the level of 10-7mm3/m. Element Cr improved the hardness, the modulus and the roughness, but reduced the wear resistance of Ti, Cr, C DLC films.

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Keywords: Magnetron sputtering; DLC film; Tribological properties

1. Introduction

It has already been demonstrated that diamond-like carbon (DLC) films exhibit a number of attractive mechanical and tribological properties (e.g. high hardness, low friction, high wear resistance, etc.), and DLC films can be used in wide areas instead of diamond films due to higher cost performance, they have been desired for an excellent candidate for tribological applications to prolong the service life of equipments in special environment.

The DLC deposition technique has been developed well since the DLC film was prepared firstly by Aisenberg in 1971[1-5], and it has been the subject of intensive studies for the last 30 years, especially about the original deposition technique and the tribological properties [2-6]. Magnetron sputtering PVD was used to prepared the DLC films because of its high deposition rate, low air pressure, high forming quality, stable technology and convenient for commercial production, and the tribological properties of the DLC films sliding against GCr15 ball at various

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loads were measured on a universal reciprocating friction and wear tester, which would provide data and method for the application of DLC films in equipment maintenance.

2. Experimental

DLC multilayer films are deposited on Si(100) wafers with the diameter of 125mm by using a mass-ion source magnetron sputtering PVD deposition system, which are mounted with three industrial targets of Cr, Ti and graphite. Prior to deposition, silicon wafer substrate is sputter-cleaned with Ar^{+} at a negative bias voltage of 1.3kV for 20 min, and then metal transition layer is deposited. Two kinds of diamond-like carbon films containing Ti, C and Ti, Cr, C were prepared by adjusting the parameters, labeled ML1~3 and ML4~6 respectively.

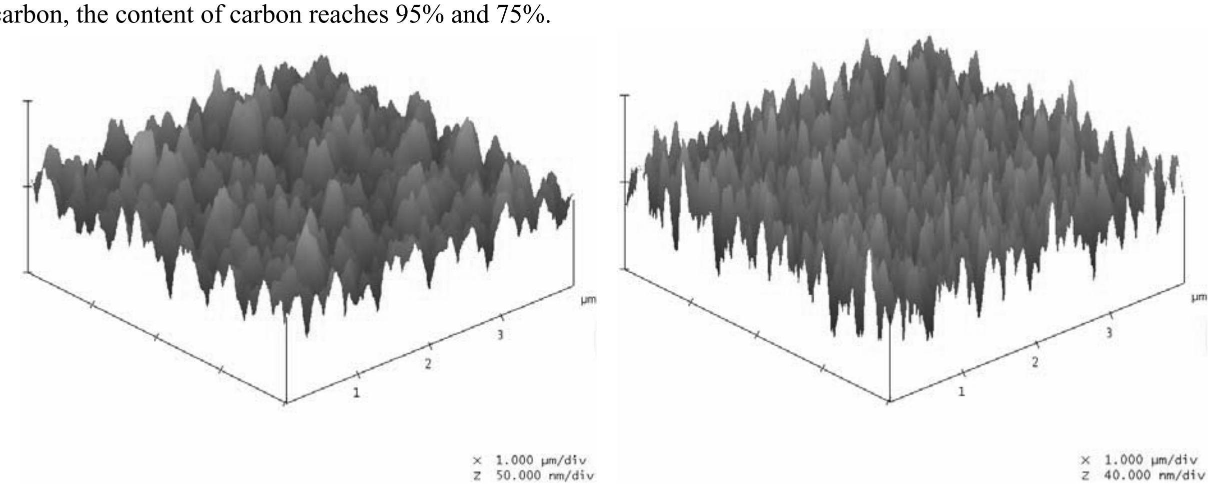
The microstructure and elemental composition of the films were characterized by atomic-force microscope (AFM) and auger electron spectrometer (AES). The hardness and modulus were analyzed by nano-indentation system (MML Corporation of UK), five indentations were made on each sample at the same condition with the depth of 150nm.

The tribological properties of the DLC films were measured on a universal reciprocating friction and wear tester (CETR Corporation of US). The tribological tests were performed in atmosphere with relative humidity in the rage of 40-45%. A 3.5 mm diameter GCr15 ball was used as the mating material. The loads on the ball were 1N, 2N, 3N, 5N and 7N respectively. The sliding distance was 10mm, and the frequency was 5Hz. The friction coefficient of the films was continuously recorded during the test. The wear of the films was determined from the wear grooves using profile-meter.

3. Results and discussion

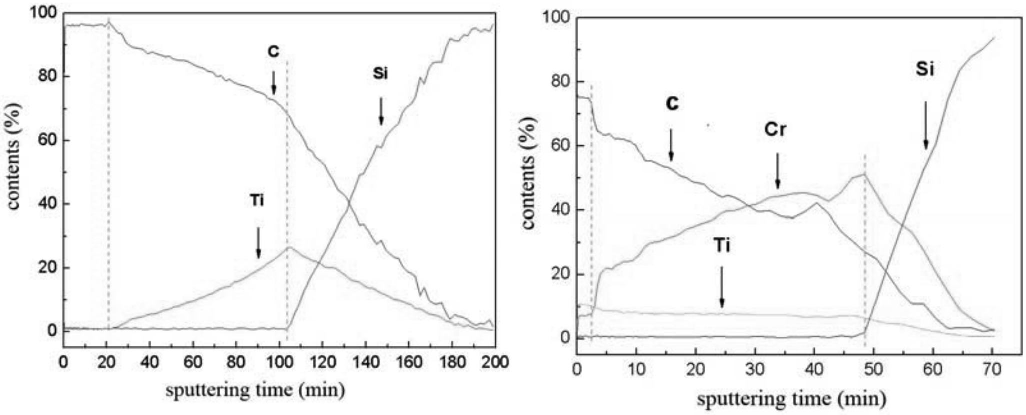
3.1 Microstructure and composition of the film

The AFM morphology of the DLC films is shown in Fig.1. It can be seen that both film surfaces are covered with oriented needle-like crystals. The surface of Ti, Cr, C film is more compact, uniform and smooth than that of Ti, C. The elements of the film are gradient distribution and the films are divided into three layers along the cross-section: rendering layer, middle layer and top layer as shown in Fig.2. The rendering layer is mainly composed of metal, which diffuses with substrate and forms better bonding area. The top layer is mainly composed of amorphous carbon, the content of carbon reaches 95% and 75%.



（a）Ti、C film （b）Ti、Cr、C film

Fig.1 AFM morphology of the DLC films



（a）Ti、C film （b）Ti、Cr、C film

Fig.2. AES of the DLC films

3.2 Mechanical properties of the film

The mechanical properties of the DLC films are shown in Table 1. It is clear that the hardness and modulus values of Ti, Cr, C films except sample ML4 are higher than those of Ti, C films, 16.58 GPa and 223.7 GPa, respectively. But the Ti, C films has higher ratio of hardness to modulus, which is related to wear resistance. The technique parameters used have litter influence on the mechanical properties of Ti, C films, while much on those of Ti, Cr, C films.

Table 1 Hardness and modulus values of DLC Films

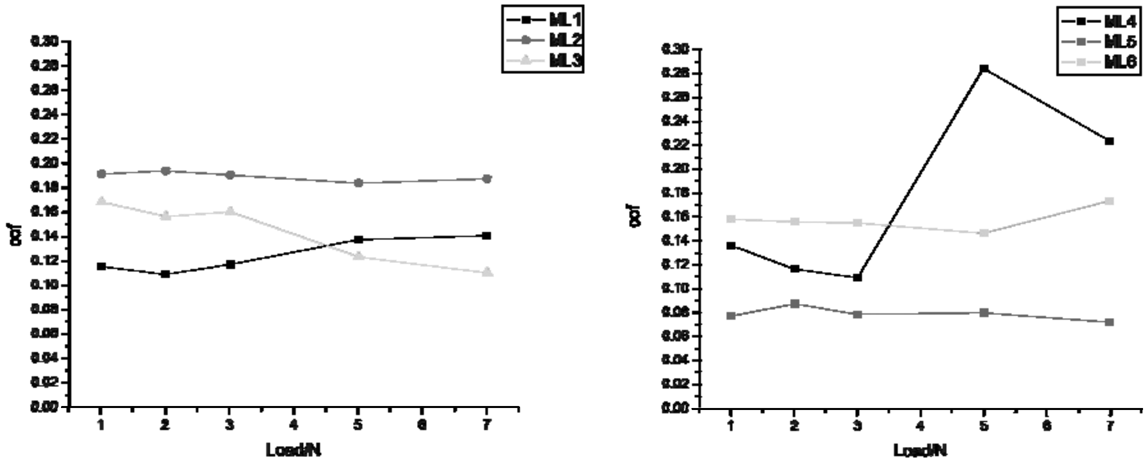
Material		Hardness H/GPa	Reduced modulus E_r/GPa	H/E_r
Ti、C	ML1	6.68±0.82	45.8±3.9	0.15
	ML2	5.06±0.22	45.5±1.1	0.11
	ML3	7.67±0.60	55.5±2.5	0.14
Ti、Cr、C	ML4	4.58±0.19	105.8±6.5	0.04
	ML5	15.11±1.93	206.6±15.2	0.07
	ML6	16.58±0.44	223.7±9.3	0.07

3.3 Tribological properties of the film

The friction coefficients of both films are shown in Fig.3. It can be seen that the friction coefficient of Ti, C films is in the level of 0.1~0.2 at various loads. However, the friction coefficient of Ti, Cr, C films is sensitive to the load, especially for sample ML4, the friction coefficient increase abruptly at the load of 5N, hence the film is worn out rapidly. In addition, the friction coefficient of Ti, Cr, C films is high at the onset of sliding, and decreases to a stable value gradually. It has been found that the hard surface has polishing function onto the ball surface, which induces higher friction coefficient at the beginning of sliding. With the sliding circle increasing, transferred layer of graphite with low shear strength is forming on the contacting area of the GCr15 ball, which makes the friction coefficient lower [8].

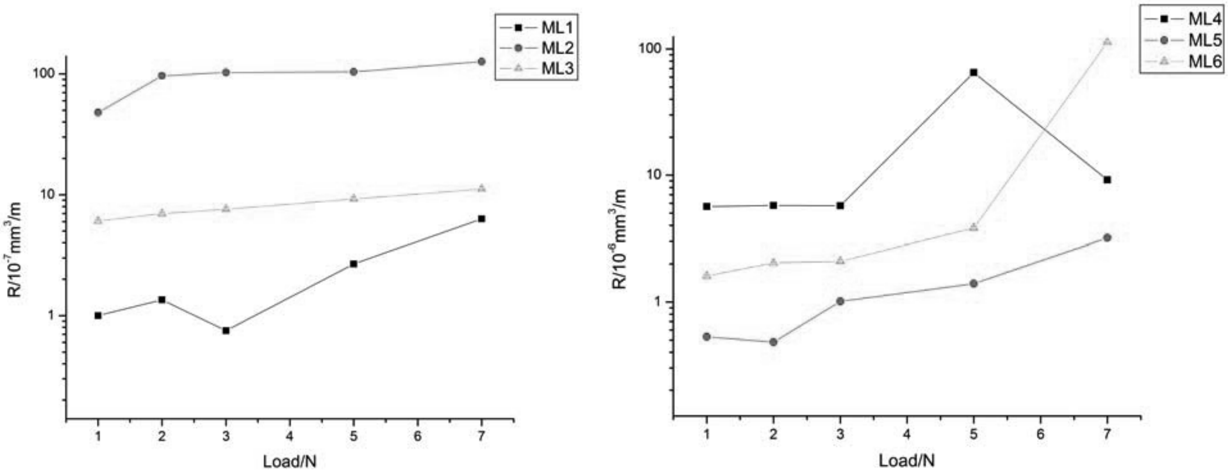
The wear rate of DLC films at different loads is shown in Fig.4. It is clear that the wear rate of all films increases with load increasing. While sample ML4 is worn out rapidly and ended the test at the load of 7N, the wear rate decreases because of short wear time. The good wear resistance of Ti, C film is obtained at different loads, the wear rate is in the level of 10-7mm3/m, in the whole, the order of wear rate shows ML1<ML3<ML2. The wear behaviors of Ti, Cr, C films change greatly at different loads, the wear rate is approximately 10-6mm3/m at low load, but it increases to 10-5mm3/m for sample ML4 and ML6 at the load of 7N, the whole order shows ML5<ML6<ML4, which is consistent with the trend of friction coefficient.

Furthermore, the ratio of hardness to modulus is related to wear resistance, the higher the ratio is, the better the wear resistance is. The Ti, C films have higher ratio of hardness to modulus than that of Ti, Cr, C films as shown in table 1, so the Ti, C films should have better wear properties, which is consistent with the result of wear test. It is found that element Cr improves the hardness, the modulus and the roughness, but reduces the wear resistance of Ti, Cr, C DLC films.



（a）Ti、C film （b）Ti、Cr、C film

Fig.3. Friction coefficient of DLC films at different loads



（a）Ti、C film （b）Ti、Cr、C film

Fig.4. Wear rate of DLC films at different loads

4. Conclusions

（1）Two kinds of diamond-like carbon films containing Ti, C and Ti, Cr, C are prepared by magnetron sputtering PVD. Gradient films are obtained by controlling the technology parameters.

（2）Ti, C films have lower value of hardness and modulus, but higher ratio of hardness to modulus and better wear resistance, the friction coefficient of which is in the level of 0.1~0.2 at various loads, the wear rate is in the level of 10-7mm3/m.

（3）Element Cr improves the hardness, the modulus and the roughness, but reduces the wear resistance of Ti, Cr, C DLC films.

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